Physical Modeling for Processing Geosynchronous Imaging Fourier Transform Spectrometer-Indian Ocean METOC Imager (GIFTS-IOMI) Hyperspectral Data

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LONG-TERM GOALS

This Office of Naval Research (ONR), Department of Defense (DoD) research effort has three main long term goals. They are: 1) to translate optimally, as well as efficiently, the physical principles of a hyperspectral data retrieval problem to the mathematical algorithms that try to solve it; 2) quantify mathematically where the useful information to complete a physically-driven application resides in the electromagnetic spectrum, and 3) develop applications of physics-based processing of hyperspectral data for surface material detection, classification and identification, atmospheric parameter retrieval formulation, and for coastal water quality assessments.

OBJECTIVES

The objective of this DoD research effort is to develop and demonstrate a fully functional GIFTS-IOMI hyperspectral data processing system with the potential for a transition to operational deployment in a centralized and/or shipboard real-time processing environment once GIFTS-IOMI is stationed over the Indian Ocean. The system will provide specialized methods for the characterization of the atmospheric and surface material components of the battlefield environment that will take good advantage of the revolutionary capabilities of the new GIFTS-IOMI mission.

APPROACH

This project will proceed through four main components designed to address the research objectives of this DoD ONR Multidisciplinary Research Program of the University Research Initiative (MURI) initiative. These components chart the evolution from an initial assessment of the GIFTS-IOMI's information content, to describing the mesoscale battlespace environment with these data (length scales between 25 and ~1000 km), and finally to the formulation of products that help characterize microscale surface features (down to 10's of meters).

1. **Mathematical Quantification of Useful Hyperspectral Information**

   - This work is being completed by UW Co-Investigators (Co-I) Dr. Jun Li, Dr. Bormin Huang, Dr. Paul Lucey, and PI Dr. Allen Huang. The proposed technical approach in spectral domain can

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14. ABSTRACT
This Office of Naval Research (ONR), Department of Defense (DoD) research effort has three main long term goals. They are: 1) to translate optimally, as well as efficiently, the physical principles of a hyperspectral data retrieval problem to the mathematical algorithms that try to solve it; 2) quantify mathematically where the useful information to complete a physically-driven application resides in the electromagnetic spectrum, and 3) develop applications of physics-based processing of hyperspectral data for surface material detection, classification and identification, atmospheric parameter retrieval formulation, and for coastal water quality assessments.

15. SUBJECT TERMS

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objectively identify the entrophy and degree of freedom information-rich radiance channels that possess the most useful information toward obtaining MURI products.

2. **Radiative Transfer Modeling** (*Clear-Sky Emission/Absorption, Atmospheric Particulate Emission/Absorption, Surface Emission/Absorption*)

   - Much preliminary work has been accomplished toward the construction of simulated data from the GIFTS instrument. This work, completed by Dr. Dave Tobin, has resulted in an improved clear-sky fast radiative transfer model for GIFTS-IOMI. Work on this aspect of the project will involve Dr. Ping Yang from the Univ. of Texas A&M. His subcontracted contributions will be toward the radiative transfer modeling of clouds and in non clear-sky conditions. Dr. Irina Sokolik (Univ. of Colorado–Boulder) will be soon funded as a subcontract to develop better dust and suspended matter parameterizations using GIFTS-IOMI radiance information.

3. **Mathematical Retrieval Algorithm Development** (*Atmospheric Parameters, Suspended Particulate Detection and Quantification, Sea Surface Temperature, Surface Material Identification*)

   - This work is in the planning stages and will rely on access to simulated GIFTS-IOMI data by Co-I's Dr. Steve Ackerman, Dr. Paul Lucey Wayne Feltz, Dr. Fred Wu, Chris Velden, Dr. Irina Sokolik, and Dr. John Mecikalski. These simulated data will soon be available to all MURI Co-I's.

4. **Product Research** (*Ocean Surface Characterization, Lower Tropospheric Temperature, Moisture and Winds, Surface Material Products, Aerosols, Derived, Second Order Products*)

   - This work is in the planning stages as Co-I's Dr. John Mecikalski, Dr. Fred Wu, Dr. Paul Lucey, Chris Velden, Wayne Feltz, and Dr. Steve Ackerman begin considering how to use simulated GIFTS-IOMI data to retrieve atmospheric profiles of temperature and water vapor, sea-surface temperature (SST) and aerosol contents to develop specific second-order products to meet DoD objectives. The UH investigators are developing products that characterize surface properties.

WORK COMPLETED

Funding through this MURI Topic #15: *"Physical Modeling for Processing of Hyperspectral Data"*, which began on 1 June 2001, has been used to plan and organize basic research for all investigators. The main planning activity occurred on 30-31 August 2001 through the *First MURI Workshop* at the UW CIMSS. This workshop brought together the DoD MURI program manager, ONR science advisors, and UW and University of Hawaii (UH) MURI investigators. Within this two-day meeting, the UW PI, Program Manager (PM), and all Co-I's obtained a more complete understanding of this MURI program from the DoD perspective, while DoD personnel developed a more complete understanding of the UW and UH facilities, the GIFTS-IOMI instrument/program, and the research expertise and investigator talents at both UW and UH. This workshop formally "launched" this MURI research effort.

In addition to the *First MURI Workshop*, the following research has began since June 2001 specific to the above tasks in the "APPROACH" section of this document. This research is detailed below for this funding period (1 June to 15 September 2001).

A physical non-linear iterative algorithm is being developed by Co-I Dr. Jun Li and the PI Allen Huang for retrieving the atmospheric temperature/moisture profiles simultaneously from GIFTS-IOMI radiance spectra. Retrieval comparisons, between those from the current GOES sounder and those using the Cross-track Infrared Sounder (CrIS) forward model, were performed to demonstrate the capability of GIFTS-IOMI soundings. Significant improvement of GIFTS-IOMI derived atmospheric profile over the GOES sounder retrieval is found. Comparing simulated GIFTS-IOMI- and GOES sounder-derived temperature and water vapor profiles with 590 independent global radiosonde profiles, RMS statistics have been generated. The GOES sounder has an accuracy of 2.0K/1 km for temperature and 25%/2 km for water vapor mixing ratio, while the advanced sounder (GIFTS-IOMI) is able to achieve 1.0K/1 km for temperature and 15%/2 km for water vapor mixing ratio, for most layers. The "physical retrieval" was found to be very important within the CrIS/GIFTS-IOMI water vapor and low-level temperature retrieval method leading to an improvement of 0.2-0.4 K for low-level temperatures and 2-5% for water vapor mixing ratio when compared to the linear regression method.

Clear-sky forward model development for GIFTS-IOMI retrievals has received much attention within this MURI to date, as performed by Co-I Dave Tobin. It involves two basic tasks: 1) Adding functionality to the existing GIFTS-IOMI fast model, and 2) Developing an improved "fast" forward radiative transfer model. Task 1 includes sub-tasks aimed at providing a useful forward model with the necessary features for producing simulated GIFTS-IOMI data for algorithm development. Since June, we have been working to package the forward model algorithm so it may be used by all MURI investigators, as well as making it flexible enough to run on several computer platforms and software languages. Regarding task 2, we are currently developing the plans that will lead to the production of an improved forward model. Two key trade studies to be done include the comparison of different monochomatic radiative transfer codes (involving differing underlying absorption physics and implementation) and different fast model parameterization schemes. We are also interfacing with the aerosol and cloud investigators within MURI to ensure compatibility between the simulation efforts. A new hire arriving in November will carry out much of the work planned under task 2.

Progress has also been made in the area of SST retrieval algorithm development. Co-I Dr. Fred Wu has performed the following work: 1) Cloud Detection: Experience indicates that uncertainty in cloud conditions is often the largest source of "random" error, whereas inadequate atmospheric correction is responsible for "consistent" error (bias). Random error can often be averaged out in climate studies but is not negligible for many Naval operations. GIFTS-IOMI affords for the first time all three approaches (spatial, spectral, and temporal) of cloud detection. It is important to make optimal use of the full potential of the GIFTS-IOMI instrument, for both theoretical and practical purposes. 2) Modeling wind-roughened sea surface emissivity (SSE) and reflectivity: We must constantly seek improvement to the SSE model as lessening the discrepancy between modeled and retrieved SSE will help the detection/identification of abnormal sea surface. Modeling sea surface reflectivity is a relatively new but potentially useful topic. Finally, 3) Atmospheric Correction: A simple regression-based algorithm will be improved upon as it will: (a) provide a quick prototype of product in case of need; (b) provide preliminary product for researches using SST as input (e.g., boundary layer turbulence, stability, and visibility), and (c) remain flexible to take advantage of development of other MURI activities (e.g., forward modeling, atmospheric profile retrievals, aerosol's impact). In Year 2, advanced SST retrieval algorithm will be the focus of research.

Research has been heavily focussed on the development of a robust method for simulating GIFTS-IOMI data. This is critical as it allows UW and UH researchers to immediately begin testing retrieval

algorithms, and developing atmospheric parameter and product algorithms during the MURI funding period (through 2004). The GIFTS-IOMI data simulation procedure first involves using a numerically generated "truth" atmospheric state from a complex mesoscale numerical weather prediction (NWP) model operating at the GIFTS-IOMI instrument resolution (4 km x 4 km). From these NWP experiments, the resultant data "cubes" are subsequently converted to interferogram information, and then to top of atmosphere (TOA) spectral radiance, of the quality expected from the GIFTS-IOMI instrument. The TOA radiance data are made to mimic the resolution of GIFTS-IOMI, and hence are presented as a 128 x 128 (4 km) array at 0.57 cm^{-1} spectral resolution with 776 radiance channels between wave numbers 685 and 1130 cm^{-1} and 1047 channels between 1650 and 2250 cm^{-1}. From these radiance spectra, simulated atmospheric state variables are then "retrieved" (e.g., vertical temperature profiles), which are quality tested against the original NWP data they were generated from. UW Co-I's Dr. Dave Tobin, Dr. John Mecikalski and another UW research scientist are heavily involved with this process. The importance of simulating GIFTS-IOMI data at this stage in the MURI research effort cannot be overstated as it allows UW and UH investigators to formulate algorithms well in advance of the GIFTS-IOMI instrument launch. Figure 1 schematically illustrates the components of the simulation process.
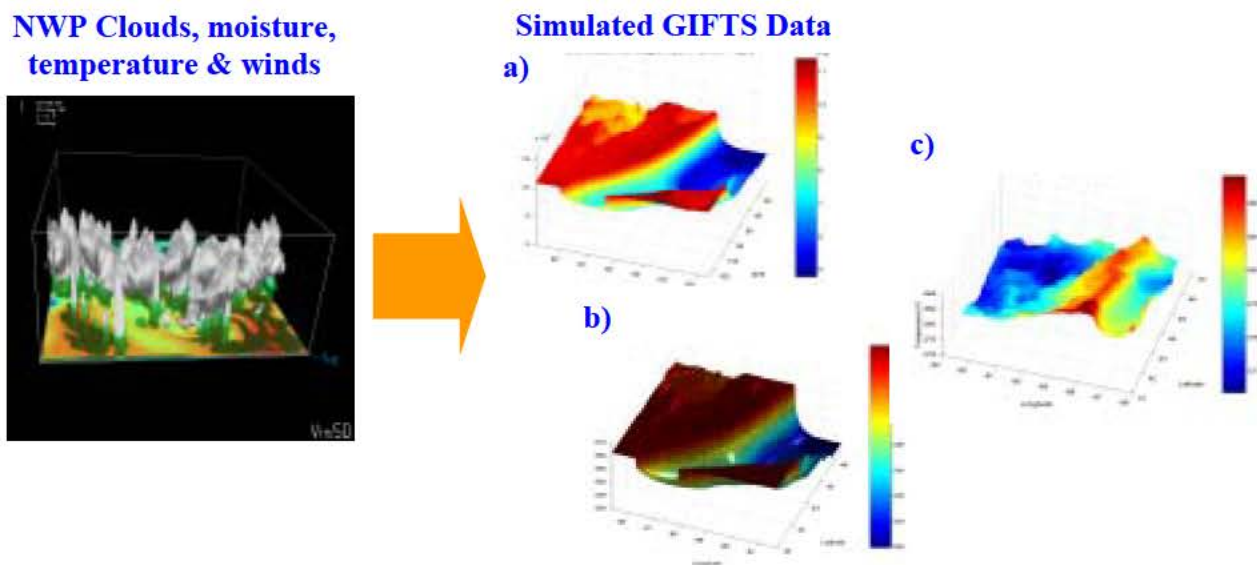

NWP Clouds, moisture, temperature & winds

Simulated GIFTS Data

Figure 1: Schematic Illustration of GIFTS Data Simulation Process
[NWP Data (left) is used to create: a) simulated GIFTS interferogram information,
b) simulated TOA radiance spectra, and c) derived brightness temperature information.]

Another major development in the early stages of this basic research effort has been the transitioning the UH longwave infrared (LWIR) Airborne Hyperspectral Imager (AHI) instrument to match the radiance spectra of the forthcoming GIFTS-IOMI instrument. This technical adjustment to this proven hyperspectral imager will allow for the immediate development and testing of algorithms applicable to GIFTS-IOMI that characterize Earth over land and ocean surfaces. Tests using the AHI at UH will occur during shortly into Year 2 of funding, with immediate UH and UW collaborative benefits.

RESULTS

The meaningful technical results since 1 June 2001 are summarized as follows:

- Development of a robust approach to simulating GIFTS-IOMI data

- First development of an improved clear-sky fast model for GIFTS-IOMI

- Initial development of a physical non-linear algorithm for the retrieval of atmospheric temperature and water vapor profiles simultaneously from GIFTS-IOMI radiance spectra

- Initial basic research to improve estimates of surface emissivity from hyperspectral data

- Transitioning of the LWIR AHI airborne hyperspectral instrument to GIFTS spectral resolution

This initial UW and UH basic research begins a systematic approach within this MURI as we transition from GIFTS-IOMI data gathering to retrieving atmospheric parameters that capitalize on the quality of GIFTS-IOMI hyperspectral data.

IMPACT/APPLICATIONS

The immediate application and impact of the basic research accomplished to date is the use of simulated GIFTS-IOMI data to formulate atmospheric parameter retrieval algorithms to form the meteorological products highlighted by DoD personnel (during the *First MURI Workshop*) as particularly valuable to Navy fleet operations.

TRANSITIONS

In this early stage of this MURI initiative, the algorithms described above for the GIFTS-IOMI instrument remain in the development stage. No person or institutions outside UW and UH are utilizing them. Within UW, Co-I's Wayne Feltz, Chris Velden, Dr. John Mecikalski and Dr. Steve Ackerman are beginning to perform the basic research necessary to form atmospheric parameter products to address the Year 2 and Year 3 proposed tasks. In addition, Co-I Dr. Paul Lucey of UH will soon coordinate with Co-I Dr. Fred Wu on basic surface characterization research as improved surface emissivity estimates are obtained. Student sharing between UW and UH and being considered.

RELATED PROJECTS

The projects that closely relate to the UW and UH MURI basic research initiative include: 1) the student and research interactions with the Univ. of Colorado–Boulder and Professor Irina Sokolik, 2) the student and basic research involvement with Professor Michael Morgan of the Univ. of Wisconsin–Madison with regards to the use of GIFTS-IOMI data for NWP, data assimilation and atmospheric parameter retrievals, and 3) the future value of this basic research to a number of UW CIMSS projects related to mesoscale nowcasting for aviation safety issues.

SUMMARY

To date, this UW and UH MURI has provided to the scientific community the first procedures for simulating and using hyperspectral radiance information from the next generation GIFTS-IOMI instrument to form atmospheric products that will describe the mesoscale battlespace. These products

will some day enhance the efficiency of Naval activities by providing to fleet highly-specialized meteorological information. The development of a first retrieval algorithm and a fast radiative transfer model for GIFTS-IOMI, and the transitioning of the AHI instrument to GIFTS-IOMI spectral resolution, highlight the progress that UW and UH have made in the first months of this MURI.